

"On the Negative After-images following Brief Retinal Excitation." By SHELFORD BIDWELL, M.A., LL.B., F.R.S.
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The experiments to be described were undertaken with the object of ascertaining the true nature of certain phenomena referred to in a recent communication, which had been left over for further examination. For full details reference should be made to the former paper,* but it will be convenient to recapitulate very shortly one or two of the results which were arrived at.

It was found that if the image of a bright object upon a dark background were suddenly formed upon the retina, the object generally appeared to be surrounded for about one-tenth of a second by a narrow red border. As a consequence of this circumstance, a black line drawn upon white paper appeared for a moment after it was first exposed to view to be entirely red. Methods were described by which these coloured borders could be seen continuously for any length of time, so that, for example, a design in black lines appeared as if drawn with red ink. The red border was explained by supposing a momentary sympathetic affection of the red nerve-fibres just outside the boundary of the luminous patch projected upon the retina. But, in some experiments, it was noticed that, when the intensity of the illumination was increased beyond a certain limit, the colour of the transient border was modified. Under very strong illumination the colour of the border was greenish-blue; sometimes (as in Experiment II, p. 371) it was of two colours—greenish-blue within and red without. It was with regard to the cause of these greenish-blue and particoloured borders that I then considered it preferable to "refrain from any speculation."

It has now been ascertained, almost beyond doubt, that the greenish-blue colour is due simply to the negative after-image of the red, this after-image being in certain cases so much more conspicuous than the red band which originates it, that the latter altogether escapes notice. The experiments upon which this conclusion is based gave results of a remarkable and unexpected character; there is no record, so far as I am aware, that anything of the kind has been previously noticed.

It should be stated that the negative after-images here referred to are of the kind which appear upon a white ground after the gaze has been directed for a time upon a coloured object. The tints of such after-images are generally said to be always complementary to colours of the objects which excite them; they are, however, rather weak or impure, being largely diluted with white light.

* 'Roy. Soc. Proc.,' 1896, vol. 60, p. 368.

Apparatus.

The only apparatus employed was a rotating disk of which one-half of the surface was black and the rest white, a sector of 45° being cut out at the junction of the black and white portions. The disk, which was 8 inches (20 cm.) in diameter, was made of tin-plate; a piece of thick brass wire was fixed along the arc bounding the open sector to restore the balance. Half the disk was covered with black velvet, for no pigment among several that were tried appeared sufficiently black in a strong light; the remaining portion of the surface was coated with white paper. The disk was turned in such a direction that the open sector was preceded by black and followed by white. It was usually illuminated by an electric lamp of 25-candle power with a ground glass bulb, the intensity of the illumination being regulated by varying the distance of the lamp; sometimes sunlight or diffused daylight was employed. The objects under examination were placed on the other side of the disk and viewed intermittently through the open sector.

Experiment I.

A card with black letters printed upon it was placed behind the disk, which was illuminated in front by the lamp at a distance of 2 feet (60 cm.). When the disk made about six turns per second, the black letters appeared to be bright red; this was of course so far merely a repetition of the old observation. The lamp was then gradually brought nearer to the disk, and as it approached the aspect of the letters underwent a change. At first they exhibited a peculiar shimmer, independently described by a great number of persons as either a "silvery," "lustrous," or "metallic" appearance; it was plainly due to flashes across the letters of some tint much lighter than the red, by which they were still mainly characterised. When the distance of the lamp was diminished to about 4 inches (10 cm.), all trace of the red had disappeared, and the letters assumed a luminous greenish-blue tint.

Experiment II.

A card was substituted upon which were printed words and figures in both black and red. It was found possible, by suitably adjusting the intensity of the light and the speed of rotation, to make such a perfect match between the letters which were actually red and those which only appeared so, that an unpractised observer could not distinguish between them. When the lamp was placed near the disk, all the letters, both black and red, appeared greenish-blue. The greenish-blue tint of the actually red letters was, moreover, more

intense or saturated than that acquired by the black ones. Bright diffused daylight produced nearly the same effect as the electric lamp at 4 inches.

These two experiments together tend to show that, whatever may be the cause of the subjective red border, the nerves of the retina when under its influence behave very much in the same way as if excited by an external red object.

Experiment III.

It was remarked in the former paper (p. 376) that the greenish-blue tint appeared to be of the hue that is complementary to red. Consideration of this fact, in conjunction with the others that have been mentioned, suggested the question whether this tint might not be referable to a negative after-image of the red border. At first sight such a supposition appeared to be an exceedingly improbable one. It is known that under ordinary circumstances a conspicuous after-image can be seen only after prolonged staring at the coloured object, and it seemed incredible that after an excitation lasting for not more than about one-fiftieth of a second there should be developed an after-image of such intensity as to completely overwhelm the primary impression, so that the latter was altogether unnoticed. When, however, the question was tested by experiment, the results were found to be consistent with the conjecture.

Several cards, measuring about 5 inches by 3, were covered with paper and silk of different colours, and observed through the opening in the rotating disk while the 25-candle power lamp was at a distance of about 6 inches. In every case the original hue entirely vanished, and was replaced by a pale tint of the complementary colour. In order to assist in the recognition of these tints, it was found useful to cover the cards with two different colours, which were approximately complementary to each other. Thus, for example, one-half of a card was covered with red silk, and the other half with green. Under the rotating disk the red portion becomes pale greenish-blue, and the green portion rose-pink, these two hues being recognized by an inexperienced person without the slightest hesitation. The immediate reversal of the colours which takes place when the disk is suddenly stopped is very striking.

It should be remarked that there is no blurring of the image upon the retina when objects are viewed through the rotating disk; even the texture of the coloured silk fabrics is seen quite distinctly. The most suitable speed of rotation is not exactly the same for all persons; the disk should generally be made to turn some six or eight times per second.

Experiment IV.

What may be regarded as the negative after-image of a black spot upon a white ground is shown by the ordinary method of observation as a patch of more intense whiteness. It was of interest to ascertain whether, by means of the disk arrangement, a black object could be made to assume a continuous appearance of abnormal whiteness.

Several broad bands $\frac{3}{8}$ inch wide were painted with "artist's black" upon a white card. When this was placed behind the rotating disk and exposed to direct sunshine, the effect was exceedingly striking, the painted portions appearing as bands of glittering whiteness upon a ground which by contrast seemed to be of a neutral grey tint. With strong lamplight or diffused daylight the phenomenon was almost equally remarkable; but, for some unexplained reason, the ground seemed to acquire a very pale purple tint instead of being, as in the former case, quite neutral.

All the above observations can, of course, be accounted for quite easily in the ordinary way by the Young-Helmholtz theory of vision. The only novelty in connection with them consists in the demonstration of the fact that the action of light after a period of darkness (which need not exceed one-twentieth of a second) can appreciably diminish the sensibility of the retinal nerve-fibres in a space of time so extremely short that if the light be coloured its colour is not consciously perceived.

The experiments clearly indicate the origin of the greenish-blue borders which I was unable to explain at the time when my former paper was written. If the hypothesis suggested in that paper is correct, it now seems that the coloured borders produced by sudden changes of illumination are, whatever their hue, in all cases primarily due to sympathetic action of the red nerve-fibres of the retina.

Note added May 6.

[The transient blue border which ordinarily appears to surround a black patch suddenly formed upon a white ground (*loc. cit.*, p. 375) becomes transformed under strong illumination into a pale red one. White letters printed upon black paper, when seen through the disk turning the reverse way, appear to be blue under ordinary illumination, and red when the lamp is brought very near the disk.—May 6.]